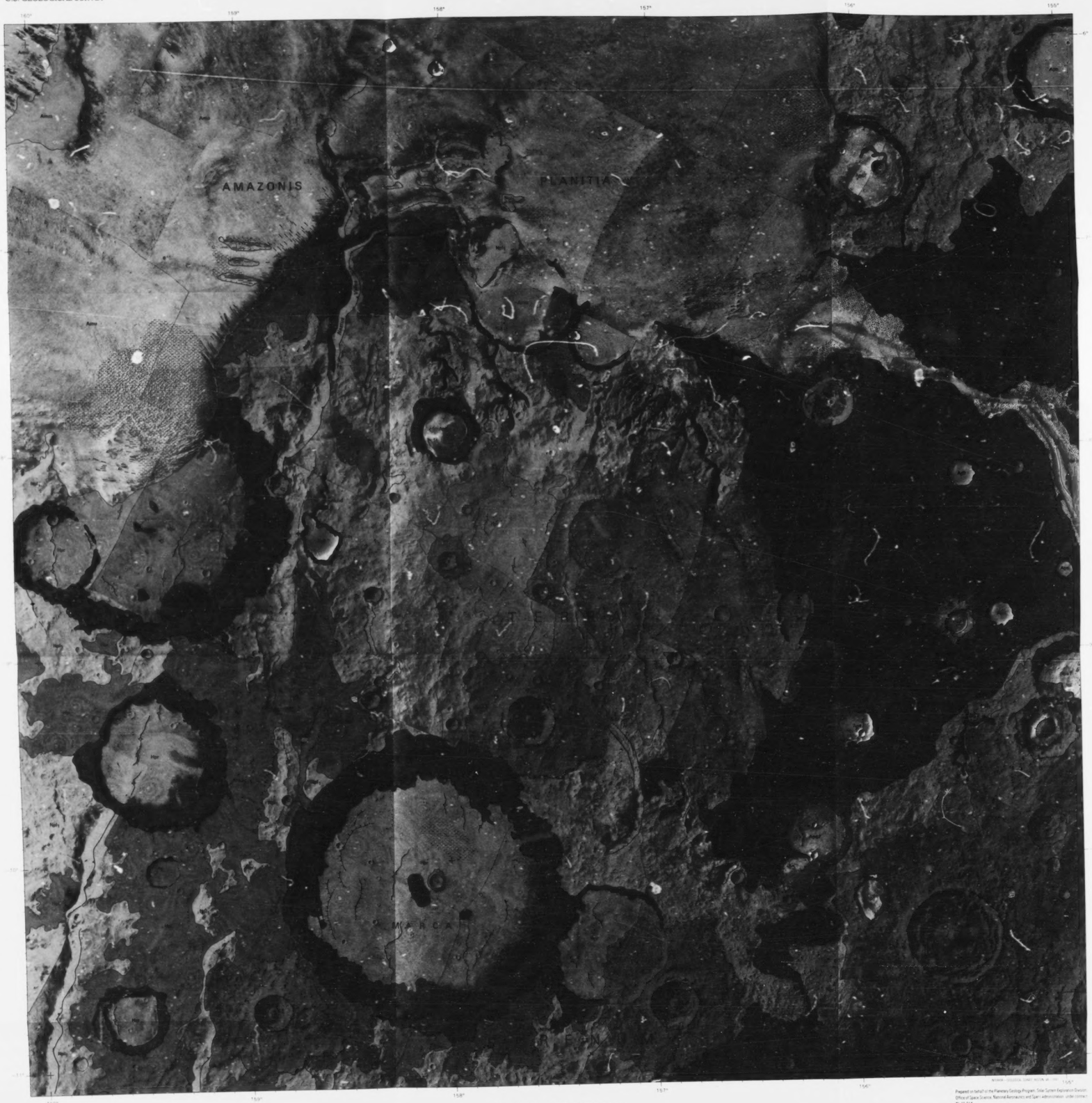
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared for the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



Base from U.S. Geological Survey (1987a, b)

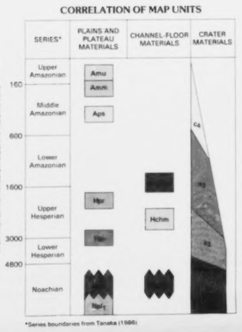
SCALE 1:502 000 (1 mm = 502 m) AT 150° LONGITUDE
TRANSVERSE MERCATOR PROJECTION

KILOMETERS

Prepared on behalf of the Planetary Geology Program, Solar System Exploration Division, Office of Space Science, National Aeronautics and Space Administration, under contract W-15,814

Manuscript approved for publication July 28, 1989

CORRELATION OF MAP UNITS



*Series boundaries from Tanaka (1986)

Intercrater plains material—On Terra Sirenum: forms fairly smooth, high albedo surface; mantles older plains units and degraded channels. Abuts c_3 crater rims and cut by theater-headed channels. Crater density 2,900±500. *Interpretation*: Eolian volcaniclastic material that may be intercalated with fluvial deposits

Knobby plateau material—On Terra Sirenum: forms local areas of irregular hummocky terrain consisting of coalesced and individual depressions partly mantled by younger materials; contains degraded channels. *Interpretation*: Knobby texture result of erosion or disruption of localized mantle superposed on heavily cratered plateau material

Heavily cratered plateau material—On Terra Sirenum; occurs as rough, heavily fractured, cratered material containing large ridges and scarps as well as depressions and degraded channels; partly mantled by younger plains materials. Crater density 40 at 40-km diameter; frequencies of smaller craters fall off steeply because they were preferentially destroyed. *Interpretation*: Early Martian crust; degraded channels may be thermokarst features formed by degradation or by thawing of ground ice

CHANNEL FLOOR MATERIALS

Material of theater-headed channels—Smooth, elongate deposits within two channels that originate at theater heads in western part of map area. Material forms lobe at mouth of one channel; lobe is concentrically ridged and overlies ridged plains material. This channel is 17 km long, 2 km wide, and 440 m deep (near mouth). *Interpretation*: Youngest fluvial deposits; water derived from ground-water sapping. Lobe is fan-deposit formed by fluvial processes; concentric ridges may indicate some additional process such as glaciation or debris flow

Material of Mangala Valles branch—Deposits within Labou Vallis, which

Contact—Dashed where approximately located; dotted where buried

Linear scarp—Line marks top of scarp; barb points downslope; dashed where approximately located

Lobate scarp—Interpreted as volcanic flow front. Ticks in flow direction

Ridge—Dashed where approximately located; dotted where buried

Wrinkle ridge—Similar to ridges on lunar maria; dashed where approximately located

Depression

Crater rim crest—Dotted where buried

Crater central peak

Streamlined ridges—Interpreted as yardangs; schematic

Clustered mounds and pits—Incipient yardangs, dunes, and blowouts

Terrace deposits

INTRODUCTION

This map is one in a series of 1:500,000-scale geologic maps initiated by the National Aeronautics and Space Administration to investigate areas of particular scientific interest on Mars. The west Mangala Valles area merits detailed geologic study because it contains several small channels whose ages can be determined relative to geologic units that range in age from early (Noachian) to late (Amazonian) periods of Martian history. Because the small channels are of three ages and channels of each age are of a geomorphic type unique to that age, their study increases our understanding of the continuity of fluvial processes in the evolutionary history of Mars. For these reasons, part of the area is a proposed site for a sample-return mission to Mars.

The map base is a composite of parts of two Viking 1:500,000-scale photomosaics

superposed craters are of many different sizes and ages (Scott and Tanaka, 1986). It is exposed as outliers of extensive masses extending for hundreds of kilometers south of the map area that contain scattered, large, north-trending ridges and scarps. The material lacks diagnostic geomorphic features such as flow fronts and wrinkle ridges that are useful indicators of lithology and origin.

Around Labou Vallis, the cratered unit surrounds local areas of irregular hummocks and hollows, mapped as knobby plateau material. This unit forms terrain consisting of both coalesced and individual depressions having steep sides and flat bottoms. The hummocks and hollows may have resulted from erosion of a localized mantle superposed on the cratered unit. The mantle may have consisted of lava sheets that broke up due to the degradation of ground ice by a process such as thermokarst; the hollows are similar in appearance to terrestrial thermokarst alases, circular or oval depressions formed by degradation or by thawing of permafrost (Czudek and Demek, 1970). Alternatively, this texture may be caused by erosion of highland material on a planetwide scale, forming "stripped terrain" (Schultz and Lutz, 1988); Schultz (1986) suggested that the erosion may have resulted from eolian stripping of possible remnant polar deposits (mapped here as the middle and upper members of the Medusae Fossae Formation).

HESPERIAN SYSTEM

Parts of Terra Sirenum are covered by a mantle of intercrater plains material (unit Hpi), which is also present in the east Mangala map area (Chapman and others, 1989). This unit is interpreted to be reworked Noachian volcaniclastic material deposited by wind, possibly intercalated with fluvial material. The interpretation is based on (1) the apparent lack of c_1-age impact ejecta and the partial absence of c_2-age ejecta, (2) the presence of older degraded channels underlying the unit, (3) the unit's irregular distribution, (4) the absence of volcanic indicators on the unit, and (5) the assumption, based on planetwide geologic mapping, that Noachian material consists of heavily bombarded volcanic deposits (Scott and Carr, 1978). The ancient impact ejecta may have been blanketed by later volcanic material or eroded away; degraded channels indicate that, in places, erosion was by fluvial processes.

A low area in the central part of the map area is locally filled by younger Hesperian ridged plains material (unit Hpr); this unit also fills large c_3 craters. Wrinkle ridges are

the Medusae Fossae Formation overlies Amazonian basaltic lava flows (Chapman and others, 1989).

CHANNELS AND HYDROLOGIC HISTORY

Many investigators have theorized that most, if not all, small Martian channels are ancient (Sharp and Malin, 1975; Pieri, 1980; Carr and Clow, 1981; Baker and Partridge, 1986), and Masursky and others (1977) have suggested that the large outwash channels range widely in age. Baker and Partridge (1986) noted that at least two episodes of channeling occurred during Noachian time in this equatorial region. Mapping in the west Mangala Valles area indicates that three separate channeling events, ranging in age from Noachian to Early Amazonian, produced three morphologically different types of small channels. Materials of these channel floors are mapped as those of (1) the degraded channel networks (unit Nchd), (2) the Mangala Valles branch (unit Hchm), and (3) the theater-headed channels (unit AHchtl).

CHANNEL TYPE 1: DEGRADED CHANNEL NETWORKS

The discontinuous, linear depressions of Deva, Varus (fig. 3B), Nestus, and Nicer (fig. 3C) Valles are the major degraded channel networks that incise Noachian heavily cratered and knobby plateau materials in the central, eastern, and southern parts of the map area. The channels are locally blanketed by the Hesperian intercrater plains and ridged plains materials and cut by Labou Vallis. They are therefore younger than the Noachian deposits and older than the two Hesperian units and the catastrophic flooding of Mangala Valles via the Labou channel (described below). These channels are 33 to 112 m deep and 0.7 to 4.0 km wide; lengths differ but may reach 80 km. Valleys are either shallow with irregular, scalloped, and partly eroded walls or deeply incised with nearly vertical walls and flat floors; channel sections are alternately wide and narrow. Some indistinct channel tributaries originate in rough, hilly Noachian terrain; some are on the flanks of ancient impact craters (25 km in average diameter); many are close to hummocks and hollows on Noachian material (fig. 3B). The presence of tributaries suggests that these channels may be runoff channels carved by precipitation; however, the discontinuous nature of their tributaries and the proximity of the channels in many

SUMMARY OF HYDROLOGIC

The three morphologically different types of small to have been formed during three separate epochs degraded channels may have been formed by subsu broad outwash channel branch formed by catastrophic Theater-headed channels appear to have formed Amazonian time by sapping alone or by sapping comb overland flow, debris flow, or glaciation.

The many channels in the west Mangala area plateau material was an available source of water, st stored as ice (Carr, 1986). (Mars now has a daily tem equator to −123 °C at the winter pole; Fanale and C 1976.) Many authors have cited numerous examples of existence of a large reservoir of ground ice on Mars (and Schaber, 1977; Rossbacher and Judson, 19 Interlayered regolith material and porous, fractured ground ice. Large volumes of water that eroded Man channel may have come from the melting of overlying heating (McCauley and others, 1972). Massively re release of large-scale floods could have been trigg volcanism (Greeley and Spudis, 1981). Alternatively, aquifer beneath a thick permafrost layer could be tra exceeded the lithostatic pressure (Carr, 1979, 19 channeling suggests intermittent hydrologic activity morphologies may further imply that certain proce dominant in or unique to specific periods in the Mars

STRUCTURE

South of the map area, east-trending bands of Mar intercrater plains and Noachian materials. These ba Hesperian and were reactivated in Late Hesperian (J Saunders, 1982; Tanaka, 1986). Water that erode Mar became appears to have emanated from the fault(s) in the of the map area (Chapman and others, 1989).

In the map area, large, north-trending, widely s cratered plateau material; they are as long as 400 km and area, these ridges are truncated by faults of Memnonia transactional with scarps of roughly the same scale photomosaic base is composed of orthographic image on its west side that is not seen on filtered versio 1:2,000,000-scale photomosaic of the area (U.S. Geo parallel, northward trends of the ridges and local str features. Noting that many Noachian ridges have a sy have interpreted the ridges to have formed along fa

North-trending wrinkle ridges are prominent feat They differ from the large Noachian ridges in that asymmetrical. These features are common on the interpretations of their origin differ (Colton and others 1973; Scott, 1978; Lucchitta, 1976; Plescia and Saunders plateau ridge systems, Watters and Maxwell (1986 explained as compressional features that formed over probably formed in conjunction with volcanic activity wrinkle ridges parallel older Noachian ridges and s and formed by lava following earlier fractures. In t thrusting and compression along zones of structural

The northeast-trending boundary to the subd highland from the Amazonian Planitia lowlands in the area, it may be covered by the Medusae Fossae Format area suggests that the scarp formed during the Late H 1989). Two small, east-trending scarps at about 4° Hesperian age, because they cut the intercrater pla Medusae Fossae Formation; the scarps appear to be small grabens.

GEOLOGIC HISTO

In the west Mangala area, the Noachian crater heavily cratered material. The Noachian terrain was inva ground-water seepage or melted ground ice, formin pitted surface texture of knobby plateau material. Sc formed large ridges that are locally transitional to scar partly covered by a mantle of Hesperian intercrater plai of reworked Noachian debris. During the Late Hesperi Memnonia Fossae to the south. The former west-flo that formed Mangala and Labou Valles. During the Ea ridged plains unit filled low areas and large craters. T map area is covered in one place by a fan deposit fro channel. The channel was produced by sapping of th formed during Late Hesperian to Early Amazonian t surfaced by poorly indurated material of Amazon Formation, which may consist of spumiform deposits

A CANDIDATE LANDI

ROUTE TRAVERSES AND SAMPL

Candidate landing sites must contain a diversity age range, that are in close enough proximity to be mobility. A site also has unique geologic features, mo Mangala Valles area includes several such sites; the two and 6.

Twenty-four sample stations are located within th landing and ascent sites are assumed to be 100 km in to the stations are provisionally laid out from the landi would be obtained (table 1), the routes agree with t obstacles at image resolutions 100 m/pixel. Those are possibly obtained from a Mars Observer or other missi the final selection of an optimum landing site and t recommended for sampling. The mostly cratered terra in parts of the traverse area may be due to a Plio-Pleis eroding off the Medusae Fossae Formation.

Like the candidate landing sites in the west M (Chapman and others, 1989, fig. 2), the other sites in 7) maximize the probability of selecting samples that fundamental questions within reasonable mission time

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ATLAS OF MARS
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WEST MANGALA VALLES REGION
M 500k -8/157 G, 1991
I-2087

Prepared for the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MARS—GEOLOGIC SERIES (SMALL SCALE)
Prepared on behalf of the Planetary Geology Program, Solar System Exploration Division, Office of Space Science, National Aeronautics and Space Administration, under contract A-15,614
Manuscript approved for publication July 29, 1989

SUMMARY OF HYDROLOGIC HISTORY

The three morphologically different types of small channels in the map area appear to have been formed during three separate episodes of channel erosion. Noachian degraded channels may have been derived by melting of ground ice. Labou Vallis is a broad outwash channel branch formed by catastrophic flooding in Late Hesperian time. Theater-headed channels appear to have formed during Late Hesperian to Early Amazonian time by sapping alone or by sapping combined with another process such as overland flow, debris flow, or glaciation.

The many channels in the west Mangala area suggest that the heavily cratered plateau material was an available source of water, which would most likely have been stored as ice (Carr, 1986). (Mars now has a daily temperature range of -53 °C at the equator to -123 °C at the winter pole; Fanale and Cannon, 1971; Kieffer and others, 1976.) Many authors have cited numerous examples of Martian features that indicate the existence of a large reservoir of ground ice on Mars (Anderson and others, 1973; Carr and Schaber, 1977; Rossbacher and Judson, 1981; Squyres, 1984; Lucchitta, 1985). Interlayered regolith material and porous, fractured basalt flows are likely hosts of ground ice. Large volumes of water that eroded Mangala Valles and the Labou branch channel may have come from the melting of interstitial ice in the subsurface by volcanic heating (McCauley and others, 1972; Masursky and others, 1977); specifically, the release of large-scale floods could have been triggered by development of Tharsis volcanism (Greeley and Spudis, 1981). Alternatively, ground water trapped in a confined aquifer beneath a thick permafrost layer could be rapidly released if the pore pressure exceeded the lithostatic pressure (Carr, 1979). However, the recurrent nature of channeling suggests intermittent hydrologic activity on Mars, and the different channel morphologies may further imply that certain processes of channel formation were dominant in or unique to specific periods in the Mangala Valles region.

STRUCTURE

South of the map area, east-trending faults of Memnonia Fossae cut both Hesperian intercrater plains and Noachian materials. These faults became active in the Early Hesperian and were reactivated in Late Hesperian to Early Amazonian time (Plescia and Saunders, 1982; Tanaka, 1986). Water that eroded Mangala Valles and their Labou Vallis branch appears to have emanated from the faults as did Hesperian basaltic lava flows east of the map area (Chapman and others, 1989).

In the map area, large, north-trending, widely spaced ridges occur on Noachian cratered plateau material; they are as long as 40 km and as wide as 5 km. South of the map area, these ridges are truncated by faults of Memnonia Fossae. The Noachian ridges are transitional with scarps of roughly the same size. One of the scarps seen on the photomosaic base (composed of orthographic images) has a false depression or graben on its west side that is not seen on filtered rectilinear images (fig. 3E) or on the 1:2,000,000-scale photomosaic of the area (U.S. Geological Survey, 1979). The pervasive, parallel, northward trends of the ridges and local scarps indicate that they are tectonic features. Noting that many Noachian ridges have steep scarps, Scott and Tanaka (1986) have interpreted the ridges to have formed mostly by normal faulting.

North-trending, wrinkle ridges are prominent features on the ridged plains material. They differ from the large Noachian ridges in that they are much smaller and are asymmetrical. These features are common on the Moon, Mars, and Mercury, and interpretations of their origin differ (Colton and others, 1972; Howard and Muehlberger, 1973; Scott, 1973; Lucchitta, 1976; Plescia and Golombek, 1986). In studies of the Tharsis plateau ridge systems, Watters and Maxwell (1986) stated that the ridges are best explained as compressional features that formed during a period of isostatic uplift. They probably formed in conjunction with volcanic deposits of ridged plains material. The wrinkle ridges parallel older Noachian ridges and scarps; either the features are volcanic and formed by lava following earlier fractures, or they are tectonic, resulting from thrusting and compression along zones of structural weakness.

The northeast-trending boundary scarp, which separates the Terra Sirenum highland from the Amazonis Planitia lowland to the north, cannot be observed in the map area; it may be covered by the Medusae Fossae Formation. Geologic mapping east of this area suggests that the scarp formed during the Late Hesperian (Chapman and others, 1989). Two small, east-trending scarps at about lat 7° S., long 158.5° may also be of Late Hesperian age, because they cut the intercrater plains unit and are overlain by the Medusae Fossae Formation; the scarps appear to be those of normal faults bounding a small graben.

GEOLOGIC HISTORY

In the west Mangala area, the Noachian cratered plateau unit consists of heavily bombarded material. The Noachian terrain was locally eroded by water derived from ground-water seepage or melted ground ice, leaving small, degraded channels and the pitted surface texture of knobby plateau material. North-trending, normal faulting also formed large ridges that are locally transitional to scarps. The Noachian units were then partly covered by a mantle of Hesperian intercrater plains material that probably consists of reworked Noachian debris. During the Early Hesperian, east-trending faults produced Memnonia Fossae to the south. The fossae were then the source of catastrophic floods that formed Mangala and Labou Valles. During the Late Hesperian, basaltic flows of the ridged plains unit filled low areas and large craters. This unit in the western part of the map area is covered in one place by a fan deposit from the mouth of a theater-headed channel. The channel was produced by sapping or composite processes and probably formed during Late Hesperian to Early Amazonian time. Amazonis Planitia was then surfaced by poorly indurated material of Amazonian age, the Medusae Fossae Formation, which may consist of ignimbrite deposits.

A CANDIDATE LANDING SITE

ROVER TRAVERSES AND SAMPLE STATIONS

Candidate landing sites must contain a diversity of geologic units, spanning a wide age range, that are in close enough proximity to be sampled by a vehicle of limited mobility. If a site also has unique geologic features, its potential value is greater. The west Mangala Valles area includes several such sites; the most promising is shown in figures 5 and 6.

Twenty-four sample stations are located within 38 km of the landing site (fig. 5). (The landing and ascent sites are assumed to be the same or close together.) Traverse routes to the stations are provisionally laid out from the landing site, where contingency samples would be obtained (table 1); the routes appear to be relatively smooth and free of obstacles at image resolution (50 m/pixel). However, much higher resolution images, possibly obtained from a Mars Observer or other missions, are considered necessary for the final selection of an optimum landing site and of rover traverses to the stations recommended for sampling. (The mostly craterless surface of intercrater plains material in parts of the traverse area may be due to a thin mantle of young eolian dust that may be eroding off the Medusae Fossae Formation.)

Like the candidate landing sites in this map area and the east Mangala area (Chapman and others, 1989, fig. 7), the other sites in the planned science study areas (fig. 7) maximize the probability of selecting samples that will answer the widest diversity of fundamental questions within reasonable mission constraints.

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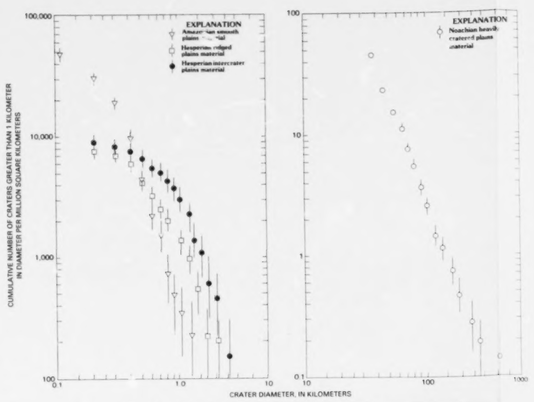

Figure 1. Log-log cumulative crater size-frequency curves for principal geologic units in map area. Bars represent standard error ($\sqrt{N}/A$, where N=cumulative number of craters and A=unit area).

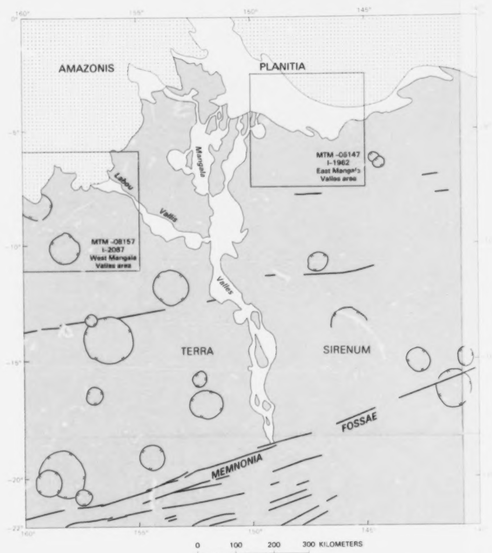

Figure 2. Index map showing location of west Mangala Valles area in relation to east Mangala area, Mangala Valles channel, Amazonis Planitia lowland, Terra Sirenum highland (shaded), principal grabens (heavy lines), large impact craters (circular outlines with ticks), and upper member of Medusae Fossae Formation (unit Amu, dotted).

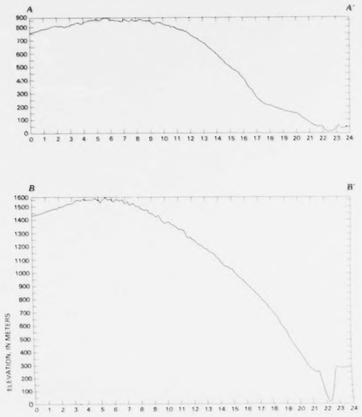

Figure 4. Photoclinometric profiles across edge of upper member of Medusae Fossae Formation. Lines of profiles shown in figure 3A.

Figure 5. Rover traverses and sample stations (numbers) in area of candidate landing site (triangle). Four traverse loops that begin and end at landing site are shown; estimated length of shortest loop is 15 km; lengths of other loops are 35, 48, and 52 km. Material of Noachian degraded channels (unit Nchd) shown in color; other unit symbols as on geologic map. Sample descriptions given in table 1. Image centered at lat 7.5° S., long 158.6°.

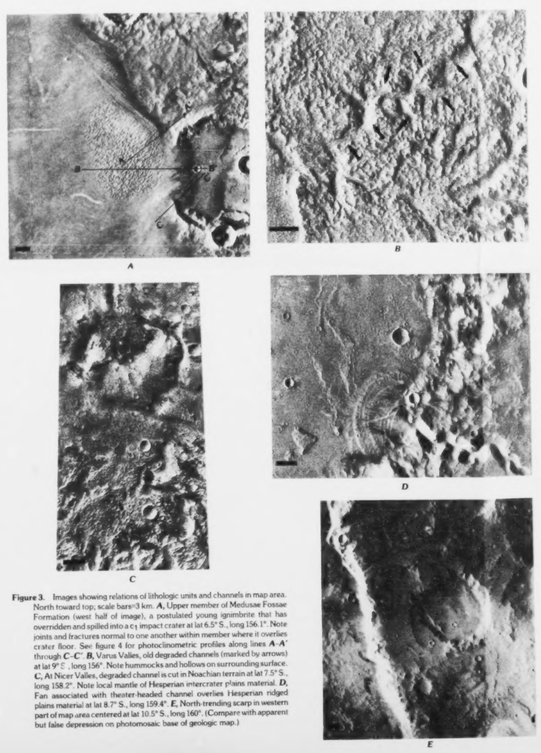

Figure 3. Images showing relations of lithologic units and channels in map area. North toward top; scale bars=3 km. ***A***, Upper member of Medusae Fossae Formation (west half of image), a postulated young ignimbrite that has overridden and spilled into a 6-km impact crater at lat 6.5° S., long 156.1°. Note joints and fractures normal to one another within member where it overlies crater floor. See figure 4 for photoclinometric profiles along lines ***A-A'*** through ***C-C'***. ***B***, Varus Vallis, old degraded channels (marked by arrows) at lat 9° S., long 156°. Note hummocks and hollows on surrounding surface. ***C***, At Nicer Valles, degraded channel is cut in Noachian terrain at lat 7.5° S., long 158.2°. Note local mantle of Hesperian intercrater plains material. ***D***, Fan associated with theater-headed channel overlies Hesperian ridged plains material at lat 8.7° S., long 159.4°. ***E***, North-trending scarp in western part of map area centered at lat 10.5° S., long 160°. (Compare with apparent but false depression on photomosaic base of geologic map.)

Figure 6. Viking high-resolution (5u m/pixel) photomosaic of north-central part of west Mangala Valles area; color processing by Alfred McEwen. North at top; area of proposed landing site (fig. 5) in lower left corner.

...scott and Tanaka, 1986). It is ...deeds of kilometers south of ...ng ridges and scarps. The ...fronts and wrinkle ridges that

...areas of irregular hummocks ...it forms terrain consisting of ...sides and flat bottoms. The ...localized mantle superposed ...s sheets that broke up due to ...arst; the hollows are similar in ...ival depressions formed by ...ek, 1970). Alternatively, this ...a planetwide scale, forming ...d suggested that the erosion ...polar deposits (mapped here ...Formation).

...crater plains material (unit ...Chapman and others, 1989). ...clastic material deposited by ...pretation is based on (1) the ...ence of eg-age ejecta, (2) the ...nit, (3) the unit's irregular ...unit, and (5) the assumption, ...material consists of heavily ...e ancient impact ejecta may ...d away; degraded channels

...filled by younger Hesperian ...craters. Wrinkle ridges are

the Medusae Fossae Formation overlies Amazonian basaltic lava flows (Chapman and others, 1989).

CHANNELS AND HYDROLOGIC HISTORY

Many investigators have theorized that most, if not all, small Martian channels are ancient (Sharp and Malin, 1975; Pieri, 1980; Carr and Clow, 1981; Baker and Partridge, 1986), and Masursky and others (1977) have suggested that the large outwash channels range widely in age. Baker and Partridge (1986) noted that at least two episodes of channeling occurred during Noachian time in this equatorial region. Mapping in the west Mangala Valles area indicates that three separate channeling events, ranging in age from Noachian to Early Amazonian, produced three morphologically different types of small channels. Materials of these channel floors are mapped as those of (1) the degraded channel networks (unit Nchd), (2) the Mangala Valles branch (unit Hchm), and (3) the theater-headed channels (unit AHcht).

CHANNEL TYPE 1: DEGRADED CHANNEL NETWORKS

The discontinuous, linear depressions of Dewa, Varus (fig. 3B), Nestus, and Nicer (fig. 3C) Valles are the major degraded channel networks that incise Noachian heavily cratered and knobby plateau materials in the central, eastern, and southern parts of the map area. The channels are locally blanketed by the Hesperian intercrater plains and ridged plains materials and cut by Labou Vallis. They are therefore younger than the Noachian deposits and older than the two Hesperian units and the catastrophic flooding of Mangala Valles via the Labou channel (described below). These channels are 33 to 112 m deep and 0.7 to 4.0 km wide; lengths differ but may reach 80 km. Valleys are either shallow with irregular, scalloped, and partly eroded walls or deeply incised with nearly vertical walls and flat floors; channel sections are alternately wide and narrow. Some indistinct channel tributaries originate in rough, hilly Noachian terrain; some are on the flanks of ancient impact craters (25 km in average diameter); many are close to hummocks and hollows on Noachian material (fig. 3B). The presence of tributaries suggests that these channels may be runoff channels carved by precipitation; however, the discontinuous nature of their tributaries and the proximity of the channels in many places to hummocks and hollows indicate that the channels may be formed by a process

Base from U.S. Geological Survey (1985a, b)

SCALE 1:502 000 (1 mm = 502 m) AT 150° LONGITUDE
TRANSVERSE MERCATOR PROJECTION

10 0 10 20 30 40 50 60 70 80 90 100
KILOMETERS

Prepared on behalf of the Planetary Geology Program, Solar System Exploration Division, Office of Space Science, National Aeronautics and Space Administration, under contract R-15,814

Manuscript approved for publication July 29, 1991

transitional with scarps of roughly the same size
photomosaic base (composed of orthographic images
on its west side that is not seen on filtered recta
1:2,000,000-scale photomosaic of the area (U.S. Geolo
parallel, northward trends of the ridges and local scar
features. Noting that many Noachian ridges have stee
have interpreted the ridges to have formed mostly by

North-trending arcuate ridges are prominent feat
They differ from the large Noachian ridges in that
symmetrical. These features are common on the
interpretations of their origin differ (Colton and others
1973; Scott, 1973; Lucchitta, 1976; Plescia and Golomb
plateau ridge systems, Watters and Maxwell (1986)
explained as compressional features that formed duri
probably formed in conjunction with volcanic depos
wrinkle ridges parallel older Noachian ridges and scarp
and formed by lava following earlier fractures, or t
thrusting and compression along zones of structural

The northeast-trending boundary scarp, whic
highland from the Amazonis Planitia lowland to the nor
area; it may be covered by the Medusae Fossae Formati
area suggests that the scarp formed during the Late
1989). Two small, east-trending scarps at about lat 7°
Hesperian age, because they cut the interpreted pla
Medusae Fossae Formation; the scarps appear to be
small graben.

GEOLOGIC HISTO

In the west Mangala area, the Noachian cratered
bombarded material. The Noachian terrain was local
ground-water seepage or melted ground ice, leaving
pitted surface texture of knobby plateau material. No
formed large ridges that are locally transitional to ang
partly covered by a mantle of Hesperian intercrater pla
of reworked Noachian debris. During the Early Hesper
Memnonia Fossae to the south. The fossae were then
that formed Mangala and Labou Valles. During the La
ridged plains unit filled low areas and large craters. T
map area is covered in one place by a fan-deposit feat
channel. The channel was produced by sapping or
formed during Late Hesperian to Early Amazonian t
surfaced by poorly indurated material of Amazon
Formation, which may consist of ignimbrite deposits

A CANDIDATE LANDIN

ROVER TRAVERSES AND SAMPI

Candidate landing sites must contain a diversity
age range, that are in close enough proximity to be
mobility. If a site also has unique geologic features, its p
Mangala Valles area includes several such sites, five na
and fi

Twenty-four sample stations are located within 8
landing and ascent sites are assumed to be the same a
to the stations are provisionally laid out from the landing
would be obtained (table 1); the routes appear to l
obstacles at image resolution (50 m/pixel). However,
possibly obtained from a Mars Observer or other missi
the final selection of an optimum landing site and ro
recommended for sampling. (The mostly crateriess na
in parts of the traverse area may be due to a thin mantle
eroding off the Medusae Fossae Formation.)

Like the candidate landing sites in this map a
(Chapman and others, 1989, fig. 2), the other sites in the
71 maximize the probability of selecting samples that
fundamental questions within reasonable mission con

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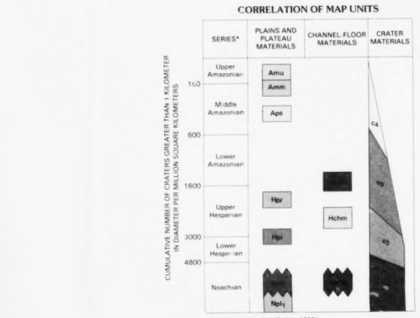
CORRELATION OF MAP UNITS



*Series boundaries from Tanaka (1986)

DESCRIPTION OF MAP UNITS

PLAINS AND PLATEAU MATERIALS

[Cumulative densities listed in the descriptions below are for craters whose diameters are greater than 1 km, normalized to $10^6 km^2$]

Amu **Upper member of the Medusae Fossae Formation**—In northern part of map area; forms nearly featureless, thick (edges are 0.6–1.0 km high), massive blanket without visible bedding; relatively high but varied albedo. Margins locally show ridges with as much as 50 m of relief, some at nearly right angles to others; unit also contains local clustered mounds and pits. *Interpretation:* Possible pyroclastic flows whose distal and upper zones are poorly lithified; ridges are yardangs; clustered mounds and pits may be incipient yardangs or eolian dunes and blowouts. Age based on stratigraphic position; crater counts on nonindurated material are indeterminate due to eolian modification

Amm **Middle member of the Medusae Fossae Formation**—In northwest corner of map area; forms featureless material; underlies upper member of Medusae Fossae Formation. *Interpretation:* Poorly indurated pyroclastic and eolian material

Aps **Smooth plains material**—Smooth deposits partly covering floors of many impact craters. Crater density 370±200. *Interpretation:* Smooth surfaces and occurrence in topographic depressions suggest eolian origin; age determined by crater density

Hpr **Ridged plains material**—On Terra Sirenum; forms relatively smooth plains in low areas and within large craters. Has wrinkle ridges, a few lobate scarps, and faint outlines of buried craters. Crater density 2,400±300. *Interpretation:* Volcanic deposits, probably basaltic in composition. Lobate scarps interpreted to be lava flow fronts

Hpi **Intercrater plains material**—On Terra Sirenum; forms fairly smooth, high albedo surface; mantles older plains units and degraded channels. Abuts c_1 crater rims and cut by theater-headed channels. Crater density 2,900±500. *Interpretation:* Eolian volcaniclastic material that may be intercalated with fluvial deposits

Hchm **Knobby plateau material**—On Terra Sirenum; forms local areas of irregular hummocky terrain consisting of coalesced and individual depressions partly mantled by younger materials; contains degraded channels. *Interpretation:* Knobby texture result of erosion or disruption of localized mantle superposed on heavily cratered plateau material

Npl1 **Heavily cratered plateau material**—On Terra Sirenum; occurs as rough, heavily fractured, cratered material containing large ridges and scarps as well as depressions and degraded channels; partly mantled by younger plains materials. Crater density 40 at 40-km diameter; frequencies of smaller craters fall off steeply because they were preferentially destroyed. *Interpretation:* Early Martian crust; degraded channels may be thermokarst features formed by degradation or by thawing of ground ice

CHANNEL-FLOOR MATERIALS

Material of theater-headed channels—Smooth, elongate deposits within two channels that originate at theater heads in western part of map area. Material forms lobe at mouth of one channel; lobe is concentrically ridged and overlies ridged plains material. This channel is 17 km long, 2 km wide, and 440 m deep (near mouth). *Interpretation:* Youngest fluvial deposits; water derived from ground-water sapping. Lobe is fan deposit formed by fluvial processes; concentric ridges may indicate some additional process such as glaciation or debris flow

Material of Mangala Valles branch—Deposits within Labou Valles, which is broad (3–11 km wide), appear morphologically fresh and contain local streamlined islands and terrace deposits. *Interpretation:* Fluvial deposits formed during catastrophic flooding that carved Mangala channels

Material of degraded channels—Smooth deposits within discontinuous, linear depressions and irregularly branching tributaries. Locally overlain by Hesperian intercrater plains and ridged plains materials. Channels dominantly shallow with sloped walls and partly eroded walls; locally may be deeply incised with flat floors. Depths range from 33 to 122 m. *Interpretation:* Oldest fluvial deposits in map area; water derived from melting of ground ice. Smooth floors and degraded walls suggest erosion and burial

CRATER MATERIALS

[All craters in map area are interpreted to be of impact origin. To avoid uneven portrayal of data, only craters larger than 3 km in diameter were mapped. Craters were assigned to four classes on the basis of state of preservation and stratigraphic control. Subscripts refer to degradation sequence]

c_4 **Material of well-preserved craters**—Bowl-shaped craters have sharp, complete rim crests and steep walls. No recognizable ejecta. Craters superposed on poorly indurated upper member of Medusae Fossae Formation. *Interpretation:* Youngest craters in map area; ejecta possibly covered by eolian material

c_3 **Material of slightly degraded craters**—Rim crests high, complete; may have central peaks; walls relatively steep; floors may be rough or smooth and some are lower than adjacent terrain; extensive ejecta superposed on Hesperian and older units. *Interpretation:* Moderately young to young crater material

c_2 **Material of moderately degraded craters**—Rim crests low, rounded; some incomplete. Floors generally flat; may be partly filled with sparsely cratered younger material; some central peaks. Modified ejecta superposed on Noachian plateau materials; ejecta may be dissected by degraded channels or buried by ridged plains material. *Interpretation:* Moderately old crater material

c_1 **Material of highly degraded craters**—Rim crests degraded and low, incomplete, or nearly absent; some central peaks; shallow, flat floors commonly filled with younger material. Rim crests in places dissected by channels. Some craters partly or completely buried by younger materials. No recognizable ejecta. *Interpretation:* Oldest crater material

Contact—Dashed where approximately located; dotted where buried

Linear scarp—Line marks top of scarp; barb points downslope; dashed where approximately located

Lobate scarp—Interpreted as volcanic flow front. Ticks in flow direction

Ridge—Dashed where approximately located; dotted where buried

Wrinkle ridge—Similar to ridges on lunar maria; dashed where approximately located

Depression

Crater rim crest—Dotted where buried

Crater central peak

Streamlined ridges—Interpreted as yardangs; schematic

Clustered mounds and pits—Incipient yardangs, dunes, and blowouts

Terrace deposits

INTRODUCTION

This map is one in a series of 1:500,000-scale geologic maps initiated by the National Aeronautics and Space Administration to investigate areas of particular scientific interest on Mars. The west Mangala Valles area merits detailed geologic study because it contains several small channels whose ages can be determined relative to geologic units that range in age from early (Noachian) to late (Amazonian) periods of Martian history. Because the small channels are of three ages and channels of each age are of a geomorphic type unique to that age, their study increases our understanding of the continuity of fluvial processes in the evolutionary history of Mars. For these reasons, part of the area is a proposed site for a sample-return mission to Mars.

The map base is a composite of parts of two Viking 1:500,000-scale photomosaics (U.S. Geological Survey, 1985a, b). These photomosaics are based on high-resolution images except in the area that now forms the northeastern part of the composite, for which only lower resolution images are available. Because the latter images were acquired at sun angles opposite those on the high-resolution images, the "mesa" that appears in this area is actually a depression. Some map units correspond or are partly equivalent to units on smaller scale maps (Mutch and Morris, 1979; Scott and Tanaka, 1986). However, in many places interpretations and contacts have been revised to reflect information visible on high-resolution Viking images; geomorphologic details on these images were clarified by spatial filtering (Condit and Chavez, 1979). The depths of channels, thicknesses of geologic units, and heights of scarps were obtained in places by using photoclinometric methods of Davis and Soderblom (1984). The relative ages of geologic units and geomorphic features such as small channels and faults were established by stratigraphic relations and supported by crater counts (fig. 1).

The east Mangala area, which contains another proposed sample-return site, has also been mapped in this series at 1:500,000 scale (Chapman and others, 1989). It lies northeast of the west Mangala map area (at lat 2.5° to 7.5° S., long 145° to 150°; fig. 2). Some plains units common to both areas have slightly different ages, although the units and their channels were dated by the same methods. Each of the two map areas contains channels of three different geomorphic types and ages, of which only two are common to both areas. (The eastern map area contains Lower Amazonian, narrow "ribbon channels" of a type and age not seen in the western area; the degraded channel networks of the western area were not observed in the eastern area.) Thus at least four types of channeling are known to have occurred at different times in the Mangala region.

GEOGRAPHIC SETTING

The map area includes the northern section of Labou Vallis (the westernmost branch of Mangala Valles) and several small channels on Terra Sirenum (fig. 2). Mangala Valles compose a north-trending channel system 850 km long and in places 150 km wide, which appears to originate at one of the east-trending faults of Memnonia Fossae that lies 530 km south of the map area, at about lat 18.5° S., long 149°. Many of the small channels on Terra Sirenum, west of the Mangala branches, also trend north. The highland-lowland boundary scarp that separates Terra Sirenum from Amazonis Planitia is covered or absent throughout the map area.

STRATIGRAPHY OF PLAINS AND PLATEAU MATERIALS

NOACHIAN SYSTEM

The oldest geologic units in the map area are the heavily cratered plateau material (unit Npl1) and the knobby plateau material (unit Nplk). The cratered plateau unit has very rough, dissected, and cratered surfaces partly mantled by younger plains materials; superposed craters are of many different sizes and ages (Scott and Tanaka, 1986). It is exposed as outliers of extensive masses extending for hundreds of kilometers south of the map area that contain scattered, large, north-trending ridges and scarps. The material lacks diagnostic geomorphic features such as flow fronts and wrinkle ridges that are useful indicators of lithology and origin.

Around Labou Vallis, the cratered unit surrounds local areas of irregular hummocks and hollows, mapped as knobby plateau material. This unit forms terrain consisting of both coalesced and individual depressions having steep sides and flat bottoms. The hummocks and hollows may have resulted from erosion of a localized mantle superposed on the cratered unit. The mantle may have consisted of lava sheets that broke up due to the degradation of ground ice by a process such as thermokarst; the hollows are similar in appearance to terrestrial thermokarst alases, circular or oval depressions formed by degradation or by thawing of permafrost (Czudek and Demek, 1970). Alternatively, this texture may be caused by erosion of highland material on a planetwide scale, forming "stripped terrain" (Schultz and Lutz, 1988); Schultz (1985) suggested that the erosion may have resulted from eolian stripping of possible remnant polar deposits (mapped here as the middle and upper members of the Medusae Fossae Formation).

HESPERIAN SYSTEM

Parts of Terra Sirenum are covered by a mantle of intercrater plains material (unit Hpi), which is also present in the east Mangala map area (Chapman and others, 1989). This unit is interpreted to be reworked Noachian volcaniclastic material deposited by wind, possibly intercalated with fluvial material. The interpretation is based on (1) the apparent lack of c_1-age impact ejecta and the partial absence of c_2-age ejecta, (2) the presence of older degraded channels underlying the unit, (3) the unit's irregular distribution, (4) the absence of volcanic indicators on the unit, and (5) the assumption, based on planetwide geologic mapping, that Noachian material consists of heavily bombarded volcanic deposits (Scott and Carr, 1978). The ancient impact ejecta may have been blanketed by later volcanic material or eroded away; degraded channels indicate that, in places, erosion was by fluvial processes.

A low area in the central part of the map area is locally filled by younger Hesperian ridged plains material (unit Hpr); this unit also fills large c_4 craters. Wrinkle ridges are prominent surface features, and the unit contains low, lobate scarps. Both features are geomorphic indicators that are commonly associated with basaltic volcanism (Greeley and Spudis, 1981; Scott and Tanaka, 1982). Furthermore, a basaltic composition for Martian lavas is consistent with independent lines of evidence, such as Viking lander data (Binder and others, 1977; Clark, 1979), Earth-based spectral observations (Singer and others, 1979), and geophysical modeling results (McGetchin and Smyth, 1978). The outlines of buried craters observed on the unit suggest that the basaltic lava flows have mantled older materials. Large impact fractures and faults may have provided pathways for magma transport.

AMAZONIAN SYSTEM

Smooth plains material (unit Aps) occurs locally on Terra Sirenum, partly covering the floors of many impact craters; lobate flow fronts and wrinkle ridges are not observed on the surface of the unit. On the basis of its smooth surface and its occurrence in topographic depressions, the unit is interpreted to be eolian deposits. (The cumulative crater density assigned to this unit was taken from counts on similar material in larger craters directly east of the map area.)

A relatively small outcrop of the middle member (Amm) of the Medusae Fossae Formation occurs in the northwest corner of the map area. It is interpreted to be poorly indurated pyroclastic and eolian deposits (Scott and Tanaka, 1986). The lowland area of Amazonis Planitia is almost completely covered in the map area by the upper member (unit Amu) of the Medusae Fossae Formation (Scott and Tanaka, 1986); this material forms a blanket having relatively high but varied albedo lapping over the cratered uplands of Terra Sirenum. The unit may be generally 2 to 3 km thick (Scott and Tanaka, 1982), but it is about 1 km thick where it spills into a crater at lat 6.5° S., long 156.1° (figs. 3A, 4). It has no visible bedding and is nearly featureless, with the exception of depressions and streamlined ridges along its margins. The ridges were interpreted by Ward (1979) to be yardangs formed by erosion of friable material. Yardang development was possibly influenced by joints and fractures, as indicated by their occurrence at nearly perpendicular angles at several locations, for example at lat 6.6° S., long 156.1° (fig. 3A). Although the origin of this poorly indurated material is not yet fully understood, Scott and Tanaka (1982) interpreted it to be an ignimbrite on the basis of its morphologic similarities to terrestrial ignimbrites. Outside the map area, for example at lat 2° S., long 157°, the unit appears to be associated with possible collapsed calderas that occur as elongate depressions near the centers of outcrops. Alternatively, the friable material has been interpreted as evidence of a previous polar position (Schultz, 1985; Schultz and Lutz, 1988) and equivalent in age to the oldest lava flows from Tharsis Montes, dated as Hesperian by Scott and Tanaka (1986). However, Schultz's age assignment of the unit does not seem likely, because east of the map area, in the vicinity of lat 4° S., long 146°, the Medusae Fossae Formation overlies Amazonian basaltic lava flows (Chapman and others, 1989).

CHANNELS AND HYDROLOGIC HISTORY

Many investigators have theorized that most, if not all, small Martian channels are ancient (Sharp and Malin, 1975; Pieri, 1980; Carr and Clow, 1981; Baker and Partridge, 1986), and Masursky and others (1977) have suggested that the large outwash channels range widely in age. Baker and Partridge (1986) noted that at least two episodes of channeling occurred during Noachian time in this equatorial region. Mapping in the west Mangala Valles area indicates that three separate channeling events, ranging in age from Noachian to Early Amazonian, produced three morphologically different types of small channels. Materials of these channel floors are mapped as those of (1) the degraded channel networks (unit Nchd), (2) the Mangala Valles branch (unit Hchm), and (3) the theater-headed channels (unit AHchl).

CHANNEL TYPE 1: DEGRADED CHANNEL NETWORKS

The discontinuous, linear depressions of Deva, Varus (fig. 3B), Nestus, and Nicer (fig. 3C) Valles are the major degraded channel networks that incise Noachian heavily cratered and knobby plateau materials in the central, eastern, and southern parts of the map area. The channels are locally blanketed by the Hesperian intercrater plains and ridged plains materials and cut by Labou Vallis. They are therefore younger than the Noachian deposits and older than the two Hesperian units and the catastrophic flooding of Mangala Valles via the Labou channel (described below). These channels are 33 to 112 m deep and 0.7 to 4.0 km wide; lengths differ but may reach 80 km. Valleys are either shallow with irregular, scalloped, and partly eroded walls or deeply incised with nearly vertical walls and flat floors; channel sections are alternately wide and narrow. Some indistinct channel tributaries originate in rough, hilly Noachian terrain; some are on the flanks of ancient impact craters (25 km in average diameter); many are close to hummocks and hollows on Noachian material (fig. 3B). The presence of tributaries suggests that these channels may be runoff channels carved by precipitation; however, the discontinuous nature of their tributaries and the proximity of the channels in many places to hummocks and hollows indicate that the channels may be formed by a process related to the melting of ground ice. The widening and narrowing of the channels could be due to coalescence of alases related to the formation of thermokarst topography. Terrestrial alases and these Martian valleys differ from river valleys in that they display unexpected turns, blind spurs, irregular tributaries, and, in places, trends against the general inclination of the relief (Czudek and Demek, 1970).

CHANNEL TYPE 2: MANGALA VALLES BRANCH

Labou Vallis, a 240-km-long, broad, shallow branch channel of the main Mangala Valles channel, cuts the Noachian knobby plateau unit and is overlain by the upper member of the Medusae Fossae Formation. East of the map area, terraces cut into intercrater plains material by Mangala Valles are overlain by an Amazonian-Hesperian volcanic unit (1,900±900 craters >1 km in diameter per $10^6 km^2$; Chapman and others, 1989). Therefore, Labou Vallis is probably no younger than Late Hesperian in age. Labou cuts degraded channels, because it appears morphologically fresher than these channels, it may be considerably younger. Like other parts of Mangala Valles, Labou is thought to be a result of catastrophic flooding (Milton, 1973; Baker and Milton, 1974; Sharp and Malin, 1975). Labou contains streamlined islands that appear fluvial in origin, and its uninterrupted connection with Mangala Valles indicates that the water that formed these islands was generated during the catastrophic flooding that carved the main Mangala channel.

CHANNEL TYPE 3: THEATER-HEADED CHANNELS

Two theater-headed channels occur in the western part of the map area. One of these channels, at lat 8.9° S., long 159.3°, cuts the intercrater plains unit, and a fan deposit at the channel's mouth overlies ridged plains material (fig. 3D). Photoclinometric profiles across the channel show it to be deeply dissected (440 m deep), 2 km across, and intermediate between u- and v-shaped in cross section. Because of their stratigraphic position, we consider these two channels to be of the same Late Hesperian to Early Amazonian age as similar theater-headed channels east of the map area (Chapman and others, 1989).

Both channels in the map area are interpreted to have formed initially by ground-water sapping, because their morphologic characteristics are common to terrestrial canyons formed by this process (Pieri, 1980; Laity, 1983; Laity and Malin, 1985; Kochel and Piper, 1986). However, east of Mangala Valles, a similar type of channel—one that lacks observable fan material; it has been compared with terrestrial channels that formed by combined surface runoff and ground-water sapping (Schumm and Phillips, 1986). The fan deposit in the map area bears concentric ridges, which may indicate that additional processes such as debris flow (producing solifluction lobes) or glaciation (resulting in moraines) may have had a minor but active role in channel formation; recessional moraines having a similar appearance occur on terrestrial glacial outwash fans such as the Northern Bagmia glacier in Alaska (Press and Siever, 1986, p. 284).

GEOLOGIC MAP OF SCIENCE STUDY AREA 1B, WEST MANGALA VALL

(SPECIAL MTM –08157 QUADRANGLE)

By

Mary G. Chapman, Harold Masursky, and Arthur L. Dial, Jr.

1991

transitional with scarps of roughly the same size. One of the scarps seen on the photomosaic base (composed of orthographic images) has a false depression or graben on its west side that is not seen on filtered rectilinear images (fig. 3E) or on the 1:2,000,000-scale photomosaic of the area (U.S. Geological Survey, 1979). The pervasive, parallel, northward trends of the ridges and local scarps indicate that they are tectonic features. Noting that many Noachian ridges have steep scarps, Scott and Tanaka (1986) have interpreted the ridges to have formed mostly by normal faulting.

North-trending wrinkle ridges are prominent features on the ridged plains material. They differ from the large Noachian ridges in that they are much smaller and are asymmetrical. These features are common on the Moon, Mars, and Mercury, and interpretations of their origin differ (Colton and others, 1972; Howard and Muehlberger, 1973; Scott, 1973; Lucchitta, 1976; Plescia and Golombek, 1986). In studies of the Tharsis plateau ridge systems, Watters and Maxwell (1986) stated that the ridges are best explained as compressional features that formed during a period of isostatic uplift. They probably formed in conjunction with volcanic deposits of ridged plains material. The wrinkle ridges parallel older Noachian ridges and scarps; either the features are volcanic and formed by lava following earlier fractures, or they are tectonic, resulting from thrusting and compression along zones of structural weakness.

The northeast-trending boundary scarp, which separates the Terra Sirenum highland from the Amazonis Planitia lowland to the north, cannot be observed in the map area; it may be covered by the Medusae Fossae Formation. Geologic mapping east of this area suggests that the scarp formed during the Late Hesperian (Chapman and others, 1989). Two small, east-trending scarps at about lat 7° S., long 158.5° may also be of Late Hesperian age, because they cut the intercrater plains unit and are overlain by the Medusae Fossae Formation; the scarps appear to be those of normal faults bounding a small graben.

GEOLOGIC HISTORY

In the west Mangala area, the Noachian cratered plateau unit consists of heavily bombarded material. The Noachian terrain was locally eroded by water derived from ground-water seepage or melted ground ice, leaving small, degraded channels and the pitted surface texture of knobby plateau material. North-trending, normal faulting also formed large ridges that are locally transitional to scarps. The Noachian units were then partly covered by a mantle of Hesperian intercrater plains material that probably consists of reworked Noachian debris. During the Early Hesperian, east-trending faults produced Memnonia Fossae to the south. The fossae were then the source of catastrophic floods that formed Mangala and Labou Valles. During the Late Hesperian, basaltic flows of the ridged plains unit filled low areas and large craters. This unit in the western part of the map area is covered in one place by a fan deposit from the mouth of a theater-headed channel. The channel was produced by sapping or composite processes and probably formed during Late Hesperian to Early Amazonian time. Amazonis Planitia was then surfaced by poorly indurated material of Amazonian age, the Medusae Fossae Formation, which may consist of ignimbrite deposits.

A CANDIDATE LANDING SITE

ROVER TRAVERSES AND SAMPLE STATIONS

Candidate landing sites must contain a diversity of geologic units, spanning a wide age range, that are in close enough proximity to be sampled by a vehicle of limited mobility. If a site also has unique geologic features, its potential value is greater. The west Mangala Valles area includes several such sites; the most promising is shown in figures 5 and 6.

Twenty-four sample stations are located within 38 km of the landing site (fig. 5). (The landing and ascent sites are assumed to be the same or close together.) Traverse routes to the stations are provisionally laid out from the landing site, where contingency samples would be obtained (table 1); the routes appear to be relatively smooth and free of obstacles at image resolution (50 m/pixel). However, much higher resolution images, possibly obtained from a Mars Observer or other missions, are considered necessary for the final selection of an optimum landing site and of rover traverses to the stations recommended for sampling. (The mostly craterless surface of intercrater plains material in parts of the traverse area may be due to a thin mantle of young eolian dust that may be eroding off the Medusae Fossae Formation.)

Like the candidate landing sites in this map area and the east Mangala area (Chapman and others, 1989; fig. 2), the other sites in the planned science study areas (fig. 7) maximize the probability of selecting samples that will answer the widest diversity of fundamental questions within reasonable mission constraints.

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Prepared on behalf of the Planetary Geology Program, Solar System Exploration Division, Office of Space Science, National Aeronautics and Space Administration. (slide control A-15,814)

Manuscript approved for publication July 28, 1989

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CHANNEL TYPE 3: THEATER-HEADED CHANNELS

Two theater-headed channels occur in the western part of the map area. One of these channels, at lat 8.9° S., long 159.3°, cuts the intercrater plains unit, and a fan deposit at the channel's mouth overlies ridged plains material (fig. 3D). Photoclinometric profiles across the channel show it to be deeply dissected (440 m deep) 2 km across, and intermediate between u- and v-shaped in cross section. Because of their stratigraphic position, we consider these two channels to be of the same Late Hesperian to Early Amazonian age as similar theater-headed channels east of the map area (Chapman and others, 1989).

Both channels in the map area are interpreted to have formed initially by groundwater sapping, because their morphologic characteristics are common to terrestrial canyons formed by this process (Pieri, 1980; Laity, 1983; Laity and Malin, 1985; Kochel and Piper, 1986). However, east of Mangala Valles, a similar type of channel occurs that lacks observable fan material; it has been compared with terrestrial channels that formed by combined surface runoff and ground-water sapping (Schumm and Phillips, 1986). The fan deposit in the map area bears concentric ridges, which may indicate that additional processes such as debris flow (producing solifluction lobes) or glaciation (resulting in moraines) may have had a minor but active role in channel formation; recessional moraines having a similar appearance occur on terrestrial glacial outwash fans such as the Northern Bamna glacier in Alaska (Press and Siever, 1986, p. 244).

Figure 1. Log-log cumulative crater size-frequency curves for principal geologic units in map area. Bars represent standard error ($\sqrt{N}/A$, where N=cumulative number of craters and A=unit area).

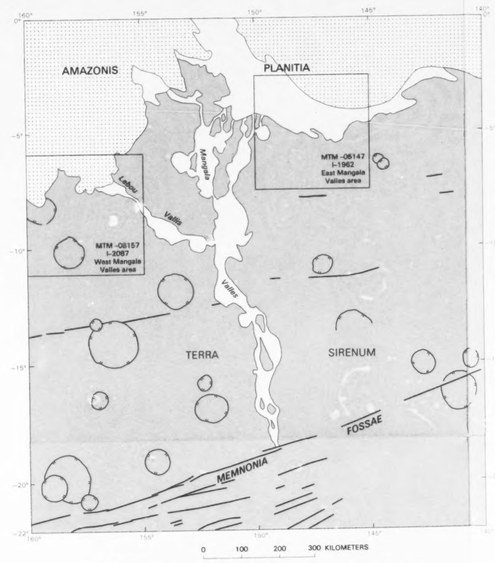

Figure 2. Index map showing location of west Mangala Valles area in relation to east Mangala area, Mangala Valles channel, Amazonis Planitia lowland, Terra Sirenum highland (shaded), principal grabens (heavy lines), large impact craters (circular outlines with ticks), and upper member of Medusae Fossae Formation (unit Amu, dotted).

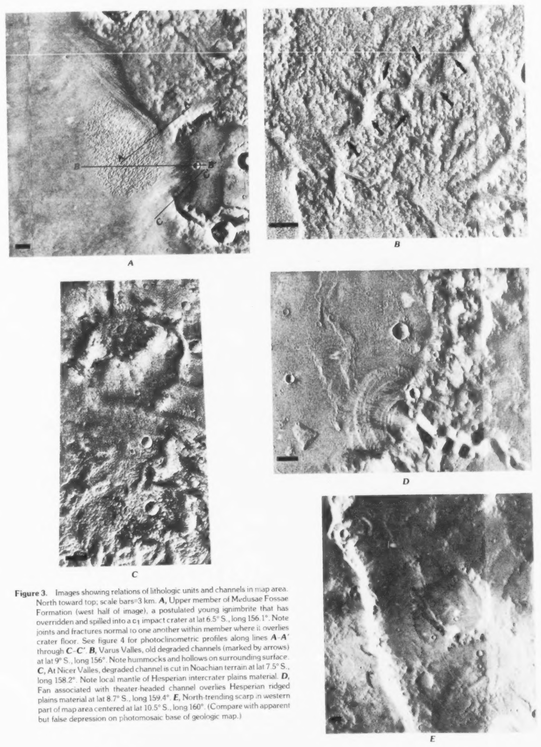

Figure 3. Images showing relations of lithologic units and channels in map area. North toward top; scale bars=3 km. **A**, Upper member of Medusae Fossae Formation (west half of image), a postulated young ignimbrite that has overridden and spalled into a c$_1$ impact crater at lat 6.5° S., long 156.1°. Note joints and fractures normal to one another within member where it overlies crater floor. See figure 4 for photoclinometric profiles along lines **A**-**A'** through **C**-**C'**. **B**, Varus Valles, old degraded channels (marked by arrows) at lat 9° S., long 156°. Note hummocks and hollows on surrounding surface. **C**, At Nicer Valles, degraded channel is cut in Noachian terrain at lat 7.5° S., long 158.2°. Note local mantle of Hesperian intercrater plains material. **D**, Fan associated with theater-headed channel overlies Hesperian ridged plains material at lat 8.7° S., long 159.4°. **E**, North-trending scarp in western part of map area centered at lat 10.5° S., long 160°. (Compare with apparent but false depression on photomosaic base of geologic map.)

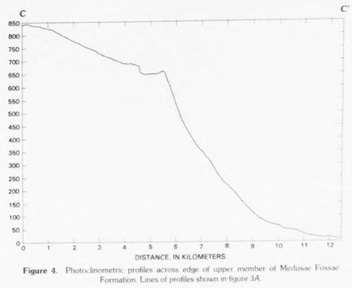

Figure 4. Photoclinometric profiles across edge of upper member of Medusae Fossae Formation. Lines of profiles shown in figure 3A.

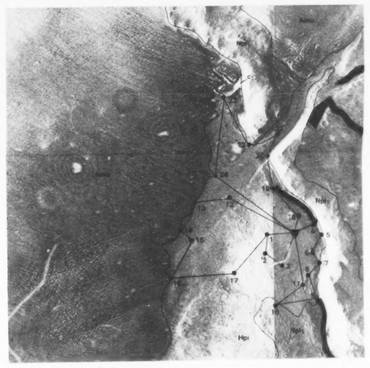

Figure 5. Rover traverses and sample stations (numbers) in area of candidate landing site (triangle). Four traverse loops that begin and end at landing site are shown; estimated length of shortest loop is 15 km; lengths of other loops are 35, 48, and 52 km. Material of Noachian degraded channels (unit Nchd) shown in color; other unit symbols as on geologic map. Sample descriptions given in table 1. Image centered at lat 7.5° S., long 158.6°.

Table 1. *Materials to be sampled at stations (numbers) of proposed landing-site (LS) traverses (fig. 5).*

Station number	Estimated minimum traverse distance from LS (km)	Sample description and geologic significance
LS	0	Eolian and possible fluvial material of intercrater plains unit (Hpi); probable volcaniclastic composition
1	4	Intercrater plains material having slightly rougher surface and higher albedo than at LS; core sample
2	6.5	Ejecta and rim material around <500-m-diameter crater
3	10	Eolian and possible fluvial material of intercrater plains unit
LS	15	Completion of first traverse
4	3	Channel material (Nchd); core sample
5	5	Heavily cratered plateau material (Npk) in talus of scarp; TV scan of scarp for evidence of layering
6	8	Local low albedo on intercrater plains material
7	10	Heavily cratered plateau material
8	12.5	Thin mantle of eolian and possible fluvial material of intercrater plains unit (Hpi) blanketing rough, heavily cratered plateau unit; core sample
9	16.5	Channel material (Nchd); core sample
10	23	Heavily cratered plateau material
11	28	Thin mantle of intercrater plains material over heavily cratered plateau unit; core sample
LS	35	Completion of second traverse
12	10	Intercrater plains material; very smooth surface due to thin mantle of young eolian dust; core sample
13	15	Possible young ignimbrite deposit (upper member of Medusae Fossae Formation, Amu); TV scan for evidence of layering, sorting, or vapor cavities
14	20	Possible young ignimbrite deposit (Amu); TV scan
15	22	Intercrater plains material having very smooth surface; core sample
16	28	Possible young ignimbrite deposit (Amu); TV scan
17	37	Intercrater plains material having a slightly rougher surface and higher albedo than at other stations; core sample
LS	48	Completion of third traverse
18	2.5	Intercrater plains material (Hpi) having darker albedo than at other stations
19	7.5	Channel material (Nchd)
20	12	Heavily cratered plateau material exposed in talus of scarp; TV scan of scarp for layering
21	15.5	Ejecta and rim material of crater 500 m in diameter
22	20	Heavily cratered plateau material
23	27.5	Rim material of c$_1$ crater
24	38.5	Possible young ignimbrite deposit (Amu); TV scan for evidence of layering, sorting, or vapor cavities
LS	52	Completion of fourth traverse
	150	Total distance of four traverses

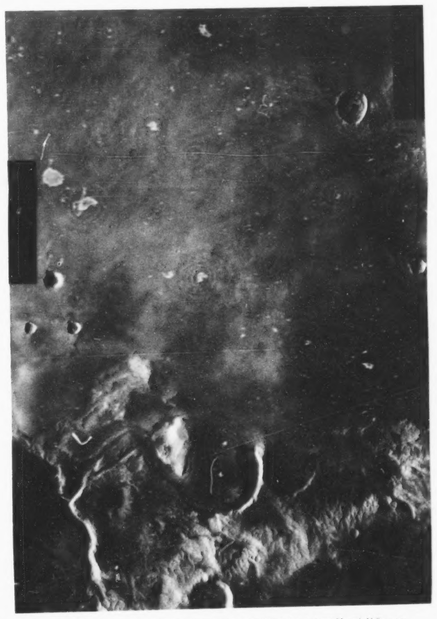

Figure 6. Viking high-resolution (50 m/pixel) photomosaic of north-central part of west Mangala Valles area; color processing by Alfred McEwen. North at top; area of proposed landing site (fig. 5) in lower left corner.

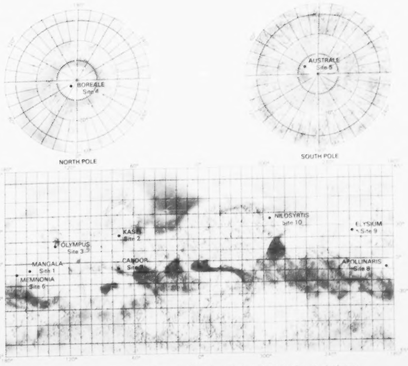

Figure 7. Planned science study areas on Mars that include candidate landing sites for future sample return missions.

OF SCIENCE STUDY AREA 1B, WEST MANGALA VALLES REGION OF MARS

(SPECIAL MTM -08157 QUADRANGLE)

By

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1991

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